How to Perform an **Arc-Flash Study** Part 2

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This is the second installment of our three-part series on how to conduct an arc-flash study in 12 steps, which started in the August issue.

Step 4: Arcing Short Circuit Calculations

Short circuit studies are traditionally performed to verify the interrupting or withstand rating of electrical components such as circuit breakers and fuses. This requires calculating the highest magnitude short circuit current, defined as a "bolted" short circuit, which assumes a solid connection with no fault impedance. When a true bolted short circuit occurs, there will be no appreciable incident energy released if equipment is properly applied because there is no arc.

When a short circuit occurs, all directly connected running motors can contribute short circuit current, which can be as large as the motor's locked rotor (starting) current. Although a single motor may not seem as though it would make a difference, many motors or a few very large motors can significantly affect the results and must be factored into the study.

Arcing Current Calculations

IEEE 1584 contains two equations for calculating the arcing short circuit current based on a known bolted short circuit current from a traditional short circuit study. This arcing current is used to determine the overcurrent device's clearing time and calculate the incident energy. Also factoring into the

equation are the system voltage, the arc gap length, and the location of the arc in a box or in air.

To calculate the arcing current for systems operating at less than 1kV, two equations are used. Equation 1 calculates the exponent of the arcing current I_a.

$$\text{Log}_{10} I_a = K + 0.662(\text{Log}_{10} I_{bf}) + 0.0966V + 0.000526G + 0.5588V(\text{Log}_{10} I_{bf}) - 0.00304G(\text{Log}_{10} I_{bf})$$

WHERE

Log_{10} = Log base$_{10}$—that is, Log_{10} of 10 = 1, Log_{10} of 100 = 2, and so on.

I_a = arcing current in kiloAmps

K = -0.153 for open air arcs, -0.097 for arcs in a box

I_{bf} = bolted three-phase RMS symmetrical short circuit current obtained from a traditional short circuit study

V = system voltage in kV

G = conductor gap (mm)

Equation 2 determines the arcing current by raising the number 10 to the power of $\text{Log}_{10} I_a$ as found in Equation 1:

$$I_a = 10^{\text{Log}_{10} I_a}$$

Although the formula looks complicated, most computer programs perform the calculations using basic data such as conductor sizes and length, motor data, transformer sizes, impedance, and utility company data. Performing manual calculations using these equations would be quite time-consuming.

When an arc occurs in open air, energy radiates in all directions, and less incident energy is concentrated towards the worker. When an arc occurs in a box, however, the energy is focused out of the box towards the worker, resulting in much higher incident energy.

The equations use two "K" factors to account for this. For arcing current calculated in open air, K=-0.153. If the arc occurs in a box, K= -0.097. Most programs simply want to know whether the arc is in a box or in open air, and they adjust the calculations accordingly. This can even be set up as default value for all locations.

Case Study of Analysis of Arcing Current

Figure 1 illustrates the single line of a simple 480Y/277V system with a panel served by an 800-Amp feeder and overcurrent device. Four different cases were calculated showing the relationship between the bolted fault current and the arcing fault current, and the effect of the arc occurring in open air or a box. Two different bolted short circuit currents were selected for comparison, a moderate magnitude of 50,000 Amps and a lower value of 15,000 Amps.

Table 1: Comparisons of Bolted and Arcing Fault Current in Air vs. Box

Case Number	Bolted Short Circuit Current	Arc in a Box or Air	Arcing Short Circuit Current
1	50,000 A	Box	26,017 A
2	50,000 A	Air	21,222 A
3	50,000 A	Box	9,303 A
4	50,000 A	Air	7,785 A

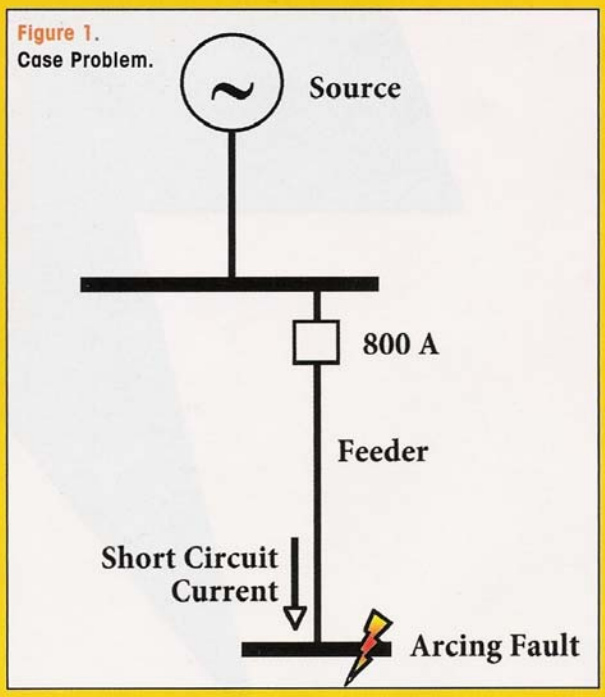


Figure 1.
Case Problem.

Table 1 illustrates the results of the four cases. The arcing short circuit for the 50,000-Amp case drops 52% to 26,017 Amps for the arc in a box as oppposed to a 42% drop to 21,222 Amps for the arc in air. The arcing current for the 15,000-Amp case is 9,303 Amps for the arc in a box as opposed to 7,785 Amps for the arc in air.

The distance of the air gap that the arc crosses, defined in millimeters as "G," affects the arcing impedance and the magnitude of the arcing current.

Even though most short circuits and arc flash events involve only one phase, the standard calculation method is based on a three-phase arc flash. This conservative approach is used because the "fireball" created when a single-phase arc flash occurs is conducting and can quickly engulf the other phases, escalating into a three-phase event.

Arcing Current above 1kV

For voltages greater than 1 kV, the following equations can be used:

$$\text{Log}_{10} I_a = 0.00402 + 0.983 \times \text{Log}_{10} I_{bf}$$

$$I_a = 10^{\text{Log}_{10} I_a}$$

These two equations, which are used for both arc in a box and arc in air, are for systems from 208 Volts to 15 kV, three-phase; 50 and 60 Hz; from 700 A to 106,000 A of short circuit current; and conductor gaps from 13 mm to 152 mm.

Step 5: Time-Current Curve Evaluation

You can determine the clearing time of the upstream overcurrent device using time current characteristics similar to those found in Figure 2. Locate the arcing current magnitude on the horizontal axis of the graph and draw a vertical line until it intersects the top of the curve. The time value is associated with the intersection point represents the device's maximum clearing time.

IEEE 1584a recommends evaluating two different levels of arcing current to determine clearing time. The first uses 100% of the estimated arc current from Step 4, and the second uses a magnitude based on 85% of the estimated arc current. Since the actual arcing currents can vary from the estimated value, using 85% of the current might reveal that a device operates more slowly depending on its time-current curve and setting adjustment. You can then compare the incident energy based on both 100% and 85% of the arcing current to see which yields the worst-case incident energy.

Step 6: Incident Energy Calculations

The 2004 edition of NFPA 70E® defines incident energy as "the amount of energy impressed on a surface, a certain distance away from the source, generated during an electrical arc event." The incident energy calculation depends on the magnitude of short circuit current and the overcurrent device's clearing time found in Steps 4 and 5. Two equations are used to determine the normalized incident energy based on a normalized 2-foot working distance and a 0.2-second device clearing time. The first is used to determine the log of the normalized incident energy, Ea:

$$\text{Log}_{10} E_a = k_1 + k_2 + 1.081 \times \log_{10} I_a + 0.0011G$$

WHERE

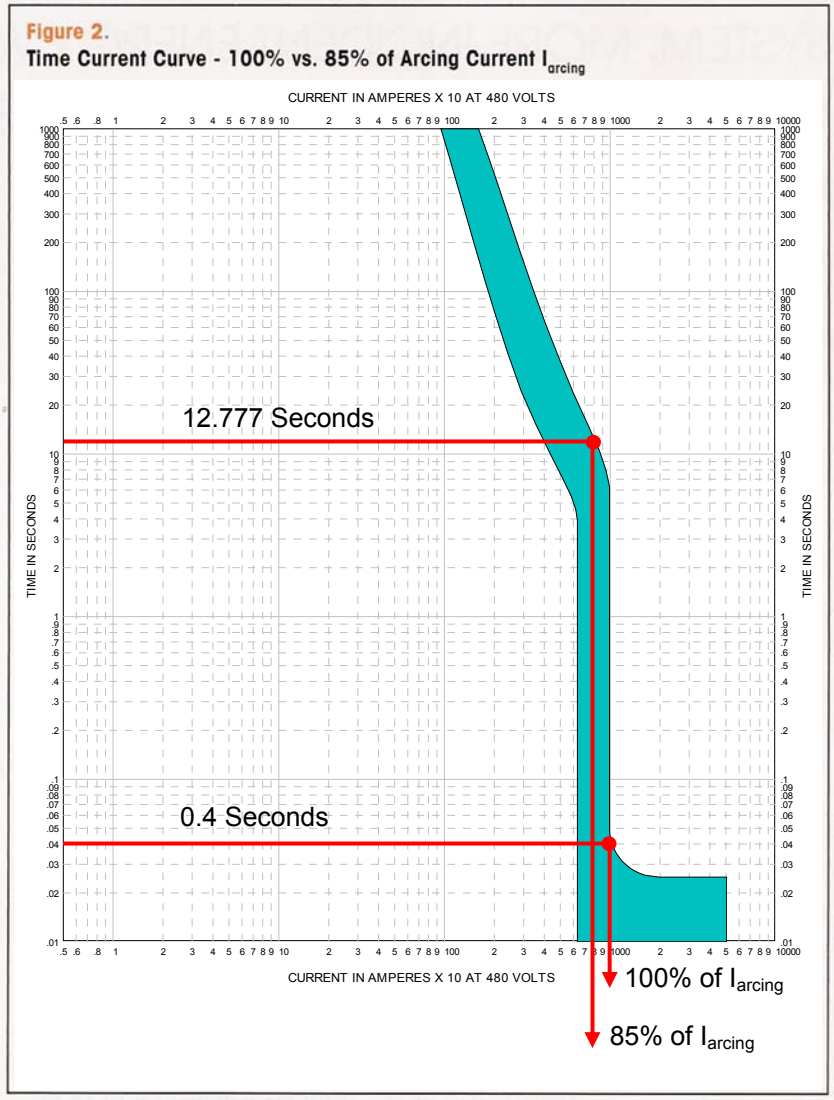
E_a = incident energy (Joules/cm^2) normalized to 2-foot working distance and 0.2-second clearing time

k_1 = -0.792 for open air arcs, -0.555 for arcs in a box

k_2 = 0 for ungrounded systems, -0.113 for grounded system

G = conductor gap in millimeters

Figure 2.
Time Current Curve - 100% vs. 85% of Arcing Current I_{arcing}



IF A **THREE-PHASE ARC FLASH OCCURS** ON AN UNGROUNDED SYSTEM, MORE INCIDENT ENERGY WILL BE DIRECTED OUT OF THE ENCLOSURE THAN WOULD BE IF THE SYSTEM WERE GROUNDED. **IF A LINE-TO-GROUND SHORT CIRCUIT OCCURS ON AN UNGROUNDED SYSTEM, SHORT CIRCUIT CURRENT DOES NOT FLOW SO THERE IS NO ARC FLASH.**

The second requires raising the number 10 to the power of $Log_{10}E_a$:

$$E_a = 10^{Log_{10}E_a}$$

Once you have calculated the normalized incident energy, you must convert it to calories/cm^2 at the specific working distance and device clearing time with a third equation:

$$E = 4.184\ C_f\ E_a\ [t / 0.2]\ [610^x / D^x]\ [0.24]$$

WHERE

- E = incident energy in cal/cm^2
- C_f = calculation factor
- E_a = incident energy normalized to 2-foot working distance and 0.2-second clearing time
- t = arcing time in seconds/from time-current curve
- D = working distance in millimeters
- X = distance exponent
- 0.24 = conversion to calories/cm^2

These equations are valid for voltages up to 15 kV with arc gaps between 10 and 153 mm. For voltages above 15 kV or arc gaps outside the equation's range, a theoretical equation is available.

If a three-phase arc flash occurs on an ungrounded system, more incident energy will be directed out of the enclosure than would be if the system were grounded. If a line-to-ground short circuit occurs on an ungrounded system, short circuit current does not flow so there is no arc flash. However, the IEEE calculations assume that the arc flash begins as a three-phase event rather than a line-to-ground event. The value of K_2 is selected based on whether the system is effectively grounded.

Working Distance

Although a person's hands will be close to the arc during an arc flash, his or her chest and head will be further back in the working distance. Because incident energy varies as the inverse square of the distance, it drops off quickly the further one is away from the arc.

The typical working distance used for panels, switchboards, and motor control centers is 18 inches. Calculations involving switchgear and higher-voltage equipment assume that hot sticks or racking mechanisms are used to keep the worker further away, and thus typically use greater working distances.

X Distance Exponent

The X distance exponent depends on the type of equipment being studied. IEEE 1584 contains a table with various X factors ranging from 0.973 for medium-voltage switchgear, to 1.641 for low-voltage panels and motor control centers, to 2.0 for open air arcs. Typically, arc flash programs ask what type of equipment is being modeled so the appropriate X distance exponent can be used.

An additional 1.5 multiplier, known as the calculation factor, may be used if the voltage is 1,000 or less. Otherwise, no factor is required.

Additional formulas exist for calculations at higher voltages and for equipment using current limiting fuses. Since properly applied current limiting devices provide an extremely quick interruption, the short circuit current will be limited, greatly reducing the incident energy.

In our next issue, we'll tackle Part Three of our three-part series on performing an arc flash study.

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